ORIGIN AND MICROMORPHOLOGICAL NOMENCLATURE OF ORGANIC MATTER IN SANDY SPODOSOLS

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INTRODUCTION

During our study of sandy spodosols from Belgium (Antwerp campine) and France (forêts de Rambouillet and Fontainebleau: West of Paris, Les Landes: Bordeaux and Aisne: Northern France), we were confronted with the fact that the terms, currently used for the micromorphological description of the organic features, did not permit an accurate description. Moreover, the meaning of the terms is neither accurately defined nor generally accepted.

For this reason we have tried to define a nomenclature, based exclusively on micromorphologically distinguishable characteristics without any reference to chemical composition. This nomenclature will be used to explain the micromorphological aspects of the podzolization in the sandy soils we have studied, especially of the organic matter in the spodic B horizon.

NOMENCLATURE

Terms have been proposed for the description of the different characteristics of soil units such as boundary, porosity, shape, degree of covering and density. These terms are:

Sharpness of the boundary. *Sharp:* knife-edge boundaries between a unit and its surroundings, especially visualized by the difference in color. *Diffuse:* gradual color transition between a unit and its surroundings.

Porosity. *Very porous:* the distance between the units is larger than the size of the units themselves. *Porous:* the difference between the units is smaller than the size of the units themselves. *Non-porous:* the units stick together completely.

Shape. *Regular:* globular; ovoid; elongate. *Irregular:* rounded (without marked angles); subangular (with rounded angles); angular (with sharp angles).

Degree of covering (for coatings). *Partial: complete.*

Density of degree of opacity. *Opaque, weakly transparent; transparent.*

Levels of the system

The nomenclature proposed is a system with three levels. *The lowest level* denotes the different kinds of organic matter.

Plant remains. Fragments of plant tissues, directly recognizable by their shape and/or their structure (Fig. 1).

(a) *Non Transformed.* The original cellular structure can be recognized, and some birefringence remains. (b) *Transformed.* The original cellular structure cannot be recognized and no birefringence is present.

The plans residues either compose isolated units in the form of fragments of large size, or are included in different units of the organic matter such as fecal pellets, aggregates and accumulations.

Elements of fragments from the fungal microflora includes hyphae, sclerotiae and spores.

Amorphous organic matter. (a) *Polymorphic organic matter* (Figs. 2, 7). Organic matter without recognizable vegetal or fungal structures. It forms a discontinuous mass formed by the juxtaposition of polymorphic elements that have a globular form, with sharp or diffuse boundaries caused by differences in color and density. (b) *Monomorphic organic matter* (Figs. 3,6).

Organic matter without recognizable vegetal or fungal structure. It forms a continuous mass with relatively uniform color and density. It is present in the form of coatings or irregular, angular or subangular units with sharp boundaries.

The second level contains the units in which the different organic materials can be assembled.

Fecal pellets (Fig. 1). Units with a regular, ovoid or spherical shape and sharp boundaries. The size varies about 25 µ to about 150 µ.

(a) *Fresh*. The fecal pellets are composed of fragments of non-transformed plant remains, still showing their structure and their original birefringence. The color is yellowish brown to brown. Their shape is perfectly regular.

(b) *Transformed*. The fecal pellets composed of transformed organic compounds and/or polymorphic organic matter. The color is brown to very dark brown.

Pellets (Figs. 1, 2, 4). Units that are essentially composed of organic matter with brown to very dark brown color. They form irregular, rounded to subangular units, with sharp to diffuse boundaries. They can be isolated, but mostly form aggregates or accumulations. The size varies from about 25 µ to 150 µ.

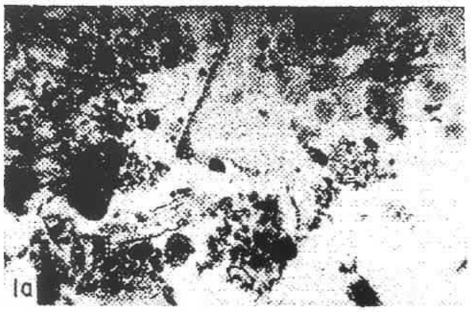
Aggregates (Figs. 2, 4). Units which have a more or less porous stacking of one or more organic compounds: non-transformed or transformed plant remains, fragments of fungal microflora, fresh or transformed fecal pellets and pellets and have clear or distinct boundaries. They may or may not be associated with fine or silt-size mineral particles. *Simple aggregates* are composed only of organic materials whilst *complex aggregates* are composed of organic materials and mineral particles.

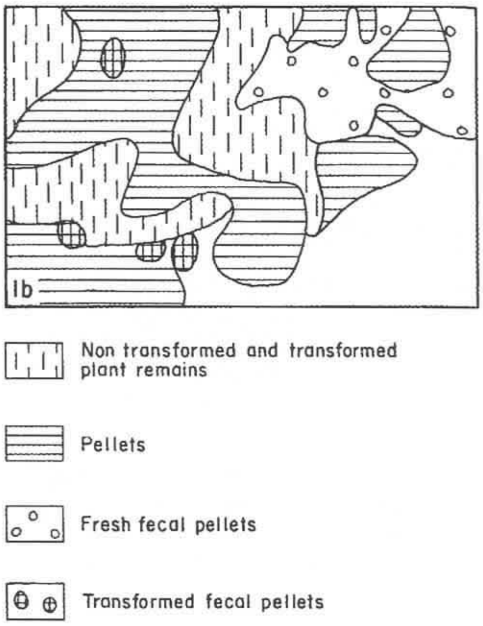
Accumulations (Figs. 5, 9) have the same composition as aggregates, but they lack distinct boundaries, being bounded mostly by skeleton grains.

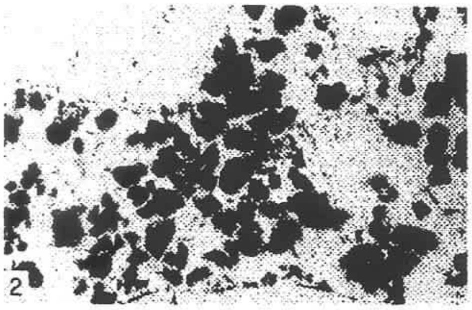
Coatings. Layers of organic matter (monomorphic or polymorphic organic matter, plant remains, fragments of the fungal microflora) that may be in combination with fine mineral particles. They cover coarse mineral compounds or other units of organic matter in such a way that their outer boundary is roughly parallel with the outer boundary of the units they coat.

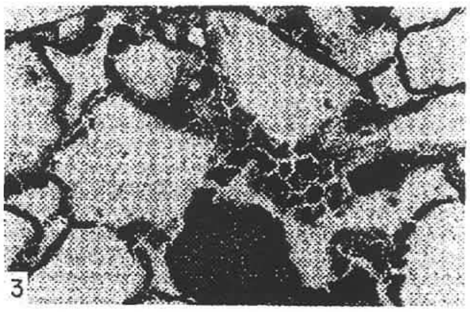
1. Uniform coating. Composed of a single kind of organic matter.

(a) *Uniform monomorphic coatings* which are composed of monomorphic organic matter (Figs. 3, 6).




1b
Non transformed and transformed plant remains
Pellets
Fresh fecal pellets
Transformed fecal pellets





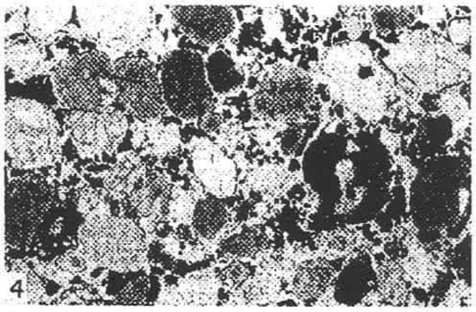
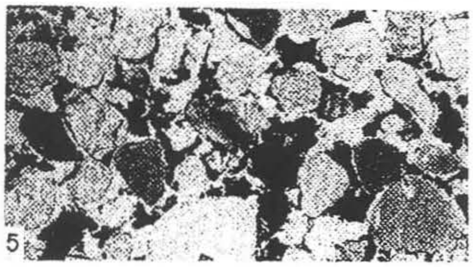


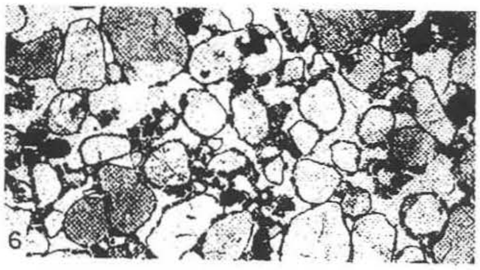
Figure 1. a and b: O_1 horizon; x 40. Fresh and transformed fecal pellets and plant remains; pellets.

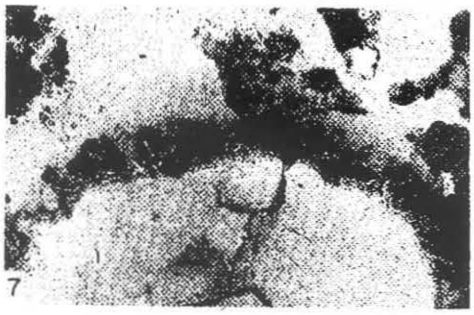
Figure 2. B_{21}h horizon; x 350. Polymorphic organic matter forming pellets.

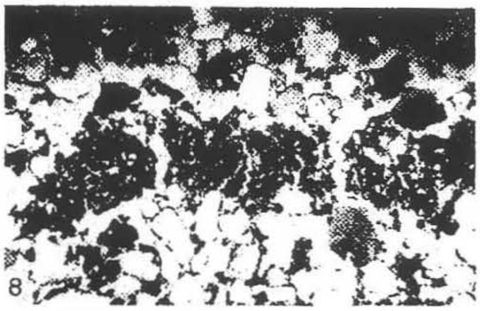
Figure 3. B_{22}hir horizon; x 100. Monomorphic organic matter forming uniform coatings and concentrations. (Coated related distribution).

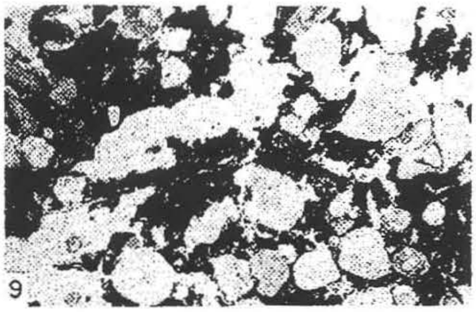
Figure 4. B_{21}h horizon; x 30. Pellets and transformed plant remains. (Juxtaposed related distribution).











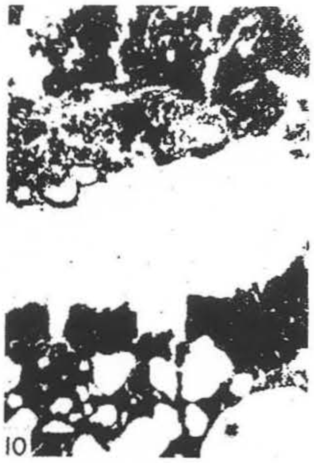


Figure 5. A_{11} horizon; x 30. Strongly coalesced pellets and polymorphic organic matter. (Linked related distribution).

Figure 6. $B_{22}h$ horizon; x 30. Monomorphic organic matter forming uniform monomorphic coatings and concentrations. (Coated related distribution).

Figure 7. B_2h horizon; x 200. Polymorphic organic matter, plant remains and fungal hyphae forming a compound coating.

Figure 8. B_2h horizon; x 40. Porous aggregates forming a cleavage striotubule. (Separated related distribution).

Figure 9. A_{11} horizon; x 30. Pellets and transformed plant remains. (Agglomerated related distribution).

Figure 10. $B_{21}h$ horizon and thin iron pan; x 40.
Upper part ($B_{21}h$) Transformed and non transformed plant remains, pellets and polymorphic organic matter. (Separated related distribution).
Lower part (thin iron pan) Monomorphic organic matter. (Filled related distribution).

(b) *Uniform polymorphic coatings* which are composed of polymorphic organic matter.

2. Compound coatings. These are composed of different kinds of organic matter (Fig. 7).

3. Complex coatings. These are composed of both organic and mineral units.

Concentrations (Figs. 3, 6).

Units composed of monomorphic organic matter, without distinct boundaries, but mostly fragmented by a network of angular or subangular cracks.

The third level is the related distribution between these units and the coarse mineral fraction, that in these soils always forms the most important part of the mineral material.

Separated (Figs. 8, 10). The organic units are present in distinct domains with little or no mixing with coarse mineral grains. This distribution is typically present in organic tubules.

Juxtaposed (Fig. 4). The organic units and the coarse mineral grains are randomly distributed, without any definite contact between each other, in a fabric that is always porous.

Agglomerated (Fig. 9). The organic units envelop the coarse skeleton grains, forming units whose external boundaries have no relation to those of the coarse grains.

Coated (Figs.3, 6). The organic units are present in the form of coatings, covering all or part of the coarse mineral grains or other organic units.

Linked (Fig. 5). Concentrations or accumulations form bridges between the coarse skeleton grains.

Filled (Fig. 10). Monomorphic organic matter fills most of the space between coarse mineral grains or the other organic units.

Summary of above considerations

Kinds of organic matter. No subdivision has been made in the *plant remains* according to their nature or origin but only according their degree of transformation, because this criterion allows one to distinguish between either a rapid turnover into fecal pellets and amorphous organic matter by the soil fauna or a slow transformation into amorphous organic matter without intervention of the soil fauna. In the first case, most of the plant remains will be non-transformed, in the second case, many will be transformed.

The organic materials that have been transformed so strongly, that both their original cellular structure and their original shape have completely disappeared are called *amorphous organic matter*. In the soils we have studied, this amorphous organic matter can basically have two origins: (1) strong transformation of the remains of plants and microflora, but without any solubilization or translocation in a liquid phase, (polymorphic); (2) solubilization or dispersion and precipitation out of the liquid phase, (monomorphic). As a result of this precipitation, coatings or bridges are formed on coarse mineral or organic particles. The polymorphic form, due to the fact that it is composed of elements of different origin and composition, never has a uniform appearance, but shows differences in color and density in the same unit and in different units. Moreover, the shape of these units and of the elements in the units is always subangular or rounded.

The monomorphic form, as a result of its transition through a liquid phase, has a more uniform color and density and can show a fine layering. Since it never forms separate units but is always present in connection with coarse grains or other units, the drying out and subsequent shrinkage results in its contraction into smaller fragments with angular or subangular shape.

Units. The different units are formed under the influence of two processes:

(a) the fauna transforms part of the organic and possibly of the clay- and silt-size mineral material into excrements, which are the origin of fecal pellets, pellets, aggregates and accumulations.

(b) solubilization of organic matter and reprecipitation giving rise to coatings and concentrations.

Fecal pellets are these characteristic excrements that show a very regular shape with a size normally between 25µ and

150µ. They are composed of plant residues that have been consumed only once and that contain no mineral material. Since one consumption does not deeply transform the plant tissues, their structure and birefringence can still be recognized clearly, at least shortly after their formation (fresh). Biochemical activity can destroy these features but without altering the regular shape (transformed). They are always present in the interior of, or very close to plant remains.

Particles of about the same size as the fecal pellets, but with a more irregular shape and a more diffuse boundary and composed of polymorphic organic matter are very common. They have been called *pellets.* Micromorphological evidence clearly shows that their formation is biological.

(1) Fecal pellets are attacked by fungi: hyphae penetrate into the fecal pellets and cause both a partial disintegration partially destroying the regular shape, and a biochemical alteration of the tissues into polymorphic organic matter.

(2) They can be formed by a subsequent consumption of fecal pellets, transformed plant remains, and even monomorphic organic matter and in this way compose the building units of clusters, together with plant remains, and possibly fine mineral material. These clusters can be porous to very porous, with the pellets present as discrete particles. However, they normally show a tendency to coalesce so that the pellets lose their individual shapes. The pellets are very common in O, A1, A2 and in many of the spodic B horizons.

In the clusters, mentioned earlier, *aggregates* and *accumulations* are distinguished, since these two units have different related distributions and different porosities, the aggregates being more porous than the accumulations.

Pellets, aggregates, and accumulations are doubtless of biological origin, i.e. excrements, originally forming granotubules or striotubules, the formation of which can be due only to the soil fauna. During the evolution, these tubules are gradually transformed into isolated aggregates and later into accumulations by compression and coalescence of the pellets. Both aggregates and accumulations are very common not only in the O but also in the A1 and A2 horizons and in most of the spodic B horizons, especially in the upper parts.

The presence of these clusters in the B horizons of the spodosols has been described extensively but mostly without a clear hypothesis about their formation: aggregation or coagulation of organic materials (Altemuller, 1962), microcrumbs or microaggregates (Kowalinski, 1969) coagulated plasma substances (Racz, 1968). Some authors, as Jongerius (1957), consider that these clusters have been mechanically translocated.

Besides the fact that the aggregates and accumulations are commonly present in tubules, which can have an horizontal orientation, more evidences can be given for the faunal origin of these units.

1. They are commonly in direct contact with decaying roots, and clearly recognizable fragments of these roots are present in the units. If they were formed by coagulation of humic substances, the presence of these fragments cannot be explained.

2. Admitting the coagulation hypothesis or the hypothesis of mechanical movement through the soil, the destruction of the plant roots can only be explained by a gradual biochemical or chemical transformation of these residues. Since spodosols are reputed to have a very low microbiological activity, this destruction would be very slow, and root remains that clearly show the original cellular structure, or at least the original shape, would be very common. But in reality, it is very exceptional to find such remnants in the A or even in the B horizons, although the rooting can be very intense. Moreover, these hypotheses cannot explain the presence of nontransformed fecal pellets at depths of 20 cm or even more; their very regular shape would surely not withstand this mechanical translocation without damaging their outer boundaries. However, some kind of mechanical transport is possible by the fauna through the formation of the numerous tubules.

3. These different points are very well illustrated by the micromorphological aspects of the spodosols that have a placic horizon or thin iron pan, between the B21h horizon and the B22 hir. Due to the impervious nature of this placic

horizon, a strong rootmat always develops above it, containing the whole range of organic materials; more or less strongly decayed roots, root remains, fresh and transformed fecal pellets, pellets and fungi, many times clustered together into aggregates and accumulations, or even forming tubules. This means that all the compounds of an O1 or an A1 horizon are present in this B horizon. Moreover the transformation of one kind of organic matter or one unit into another can be established very clearly, for example the transformation by fungi of fecal pellets into pellets.

4. Monomorphic organic matter, that is the other component of the spodic B, clearly shows the features of a material, translocated through a liquid phase: it forms layered coatings and bridges, which are very similar with clay illuviation cutans or argillans.

These different units of organic matter: at one side the polymorphic aggregates and accumulations, at the other side the monomorphic coatings and concentrations, can be present at the same place in the same horizon, closely adjacent to each other. For example, almost all the coarse grains of an horizon can be covered with a monomorphic coating but a few, forming a fine channel, lack it and have few aggregates. Admitting that these two forms of organic matter have been formed by illuviation, they must have been formed at the same time since they occupy the same level in relation with the coarse grains. This would mean that these two forms would be formed in the same conditions, which seems very improbable if not impossible.

The composition of the *coatings* can be widely divergent. *The uniform monomorphic coating* is composed of what has been called extensively "amorphous" or "dispersed" humus. It is given as the classical micromorphological characteristic of the spodic B horizons, although many of them lack it completely. When present, it is best developed in the lower part of the spodic B (B22h-B3) and in the lamellae which are very frequent underneath the B. However, we have found it in organic lamallae in the A2 of the spodosols, although rather exceptionally. As mentioned before, these coatings show the most striking features of illuviated material covering all the coarse elements with a layer of constant thickness, smoothing the irregularities of the surfaces of these elements and commonly showing a layering. Scanning microscope indicates that they are composed of irregular angular platelets, lying on the surface of the sandgrains. The surface of these platelets shows a certain similarity with the surface of an argillan.

The uniform polymorphic coating mostly has a composition of very dark brown to black, rounded to globular particles in a paler matrix. It can consist of more or less coagulated pellets sticking to the surfaces of coarse elements. They are present almost exclusively in the A horizons and the upper part of some spodic B horizons. Their formation is due either to the adhering of pellets to the surface of the skeleton grains and their subsequent transformation or to the evolution of monomorphic coatings. Indeed many times it seems that in the upper part of the profile, these coatings and pellets are losing part of their composing materials by leaching. The dark particles present in the polymorphic coatings are composed of the substances resisting the dissolution.

Compound coatings are formed by inclusion of plant remains or fragments of fungi in monomorphic or polymorphic coatings, whilst *complex coatings* are probably formed by compression of aggregates and accumulations, containing clay and silt-size particles, on the coarse mineral particles.

In many cases, the coarse skeleton grains are covered by a free grain argillan before the formation of the organic complex coating. Since these two coatings belong to a different pedogenetic process, such a feature cannot be considered as a complex coating, but has to be distinguished as a double coating. The concentrations are clusters of fragments formed by the cracking of bridges of monomorphic organic matter between coarse mineral grains or other organic units.

STAGES OF EVOLUTION OF THE SANDY SPODOSOLS AND THEIR MICROMORPHOLOGICAL FEATURES

In the spodosols on sandy materials that we have studied, we can distinguish the following stages in the evolution of the morphology of the spodic B horizons. In a previous study (De Coninck et al., 1964), we have shown the influence of free iron on the profile development in the Antwerp Campine. The subsequent research on the sandy soils in France (Righi, 1969; De Coninck et al., 1969; Robin, 1970; De Coninck et al., 1972) has indicated a similar importance in all studied soils.

I. The parent material contains free iron in evenly distributed form.

1. The first stage is the formation of a B horizon of both iron and organic matter, called Bs or Bir by many authors, having hues of 10YR or 7.5YR, with values of 6 to 4 and mostly chromas of 4 to 6, sometimes 3. This horizon is always loose, and has many roots. It develops just underneath the surface, but starts moving downward at some time, giving rise to an A2 horizon, mostly with chromas of 3 or sometimes 2, (dry) not strongly bleached. Contents of free iron (± 0.5%) and organic matter (± 1%) are low.

2. The color of the B horizon shows a darkening, especially in the upper part (10YR 3/4 to 3/2), due to an increase of the organic matter, the lower part retaining more or less the original color and the same amount of free iron as in stage 1. This differentiation gives rise to two subhorizons, a B21 and a B22. The transition between both horizons is gradual or interrupted and the rooting still intensive throughout the whole B horizon.

3. The bulk of the B horizon is gradually cemented, the sand grains being covered with a dark brown to dark reddish brown coating (10YR to 5YR 3-3/2-2). The upper part of the horizon shifts to a more greyish tinge. If an A2 is already present, its color reaches a very low chroma (1 or 0). The rooting decreases very strongly in the B horizon. The organic matter content does not show a strong increase. Under the B horizon, subhorizontal, dark brown, organic lamellae develop, many times to a great depth.

4. The upper part of the spodic B gradually loses its iron and a continuous thin iron pan is formed somewhere in the B horizon, commonly composed of two or even more separate lay-

ers of iron at a distance of a few mm. Above this iron pan, due to its imperviousness, a rootmat develops and the part of the spodic B above this pan is transformed into a sub-horizon with a greyish black or black color, with a high amount of organic matter, and low free iron content. In this way, the spodic B is divided into an upper B21h, and a lower B22h, with an abrupt and regular boundary, formed by the thin iron pan. The B21h has a high amount of organic matter (up to 10%) but a very low amount of free iron; the iron pan has 2-3% free iron and about double this amount of organic matter, while in the B22h, 2 to 3% of organic matter and 0.5 to 0.5% of free iron are present.

The micromorphological features of the B horizon in the successive stages can be summarized as follows. The first stage is characterized by the presence of a complex coating (organic and mineral) or compound coating, covering incompletely the skeleton grains, and of complex aggregates and accumulations. These different units of organic matter all have a pale brown or yellow brown color, and under the microscope it is not possible to distinguish the presence of the free iron in isolated form. The darkening during the second stage is due to formation of dark brown aggregates and accumulations, especially in the upper part of the B horizon. Many roots in different phases of faunal destruction can always be noticed in the two first stages.

In stage 3, thick, brown to very dark brown, monomorphic coatings and concentrations are formed, especially in the lower part of the B, while the aggregates and accumulations coalesce and are transformed into a very dark amorphous mass, in which the polymorphic character disappears partially and which can be covered by the monomorphic coatings. The dark lamallae, under the B horizon, are composed of monomorphic coatings and concentrations.

In stage 4, the thin iron pan presents a filled related distribution of a dark brownish red to dark red monomorphic organic matter, commonly including plant remains. Above it, the monomorphic coatings are disappearing gradually and seem to be transformed, together with fragments of fresh roots, into aggregates and accumulations. These units can be present as typical pedotubules. Non transformed roots are always plentiful. The uncovering of the skeleton grains causes the greyish tinge (low chroma) of the B21h.

II. The parent material does not contain free iron.

1. A loose friable, mostly brown to dark brown (10YR 4/3 to 2/2) B horizon, having only organic matter, is formed just underneath the A1 horizon. It can move downwards, giving rise to an A2 horizon with a rather low chroma (2, sometimes less). The B horizon has many roots, and has a rather low organic matter content (1-2%).

2. The B horizon acquires a dark reddish brown to black (5YR3/2 to 2/1) color and is cemented, the sand grains being completely coated by organic matter. This horizon always has a tendency to form to great depth, and commonly shows a succession of darker lamellae, which can coincide with finer or coarser layers. An A2 can develop. If this horizon is present it has a chroma of 2 or 1. The content of organic matter shows only a slight increase to 2-3%.

3. As in the soils with free iron in evenly distributed form, the cementation of the B causes a concentration of roots in its upper part, and the development of a B21h with a more greyish color (10YR2/1-3/1) in which pellets of organic matter and non coated sand grains are juxtaposed, and which can be distinguished from the underlying, more cemented part (B22h). Since no free iron is present, no continuous thin iron pan can be formed, and the boundary between the two subhorizons is irregular or broken. Moreover, the deepening of this B21h is not so strongly limited as it is in the soils with iron pan, so that it is generally thicker than in these profiles, but has a lower organic matter content (2-4%). In this development sequence, the micromorphological characteristics at the successive stages are very similar to sequence I. In the B21h the amount of aggregates and accumulations is much lower and their color is paler. In the lamellae, the monomorphic coatings and concentrations are thicker and darker than in the adjacent material.

The parent material contains free iron but in the form of mottling.

Organic matter is deposited in the zone that does not contain free iron, but between the iron mottles, so that, the mottles are gradually incorporated into the spodic B. Moreover the organic matter causes a contraction of the mottles which originally have a rather low free iron content, into concretions or nodules containing a high amount of iron, together with organic matter. In this way, a spodic B is formed containing both organic matter and iron, the last one present only in the form of isolated nodules and concentrations, these last features being remnant of a preceding process of soil formation.

DISCUSSION

In general, the absence of free iron or the form in which it is present, is determined in the first place by the drainage. When no watertable is present, evenly distributed free iron is normally present, so that development is characteristic for well or excessively drained soils. Parent material without free iron is typical for some soils with a high watertable but either situated in small, isolated depressions in the Belgian Campine (so called primary podsols, De Coninck et al., 1964) or on very coarse sand (The Landes, France). However, in some places, free iron can be completely absent even in well drained soils and in this way, well drained spodosols can develop the features, considered as being characteristic for hydromorphic spodosols. Mottled parent materials are a result of a preceding pedogenetic process under the influence of a periodic high watertable.

It is clear that the different stages in the 3 sequences can show strong differences in intensity and duration, depending on the conditions of the surroundings and the nature of the parent material, and that the thickness and intensity of development of the different horizons depend on these differences. Before the cementation starts, the B horizon gradually develops to a greater depth, but without reaching a high content in organic matter. The development of the A2 horizon can follow this deepening of the B, but does not necessarily do so. When the formation of the monomorphic organic matter becomes predominant, causing the cementation of the horizon, rooting is strongly impeded.

Moreover, it seems that the presence of evenly distributed free iron oxides prevents a deep migration of the monomorphic organic matter, causing it to precipitate close to the top of the pre-existing Bhir, and forming an impermeable layer, the effect of which is further enhanced by the formation of the thin iron pan. However, if no free iron is present, the migration of the monomorphic organic matter is less hindered and the Bh forms to a greater depth. This statement clearly agrees with the conclusions of the experimental work of Dechaufour and collaborators (Bruckert, et al., 1969; Bruckert, 1970; Duchaufour, 1972) on the podzolization in the Vosges.

The formation and precipitation of the monomorphic organic matter causes a "fossilization" of the profile since it strongly impedes the penetration of the soil by roots, fauna and the soil solutions, which means that subsequent evolution will be very slow; when the precipitation of monomorphic organic matter starts to be predominant at the moment the Bhir is still very close to the surface, the A2, B21h and B22h will be thin, but very strongly expressed. It seems that this is the reason of the rather shallow development of most spodosols in well-drained conditions. However, this is not an absolute characteristic of well-drained spodosols. In some of the soils we have studied on sands with ±0.3% free iron, the A2 and the B both have a thickness of ± 30 cm, but in these soils no coated related distribution of monomorphic organic matter can be noticed in the B horizon. This means that due probably to the vegetation, these soils have been in stages 1 and 2 for a long time, without formation of monomorphic organic matter.

CONCLUSIONS

In most studies and theories about podzolization, the formation of the B horizons is considered as the result of a process of illuviation: soluble organic substances, originating from the litter, complex Al and Fe in the upper part of the profile and these complexes migrate and precipitate at some depth. This micromorphological study clearly shows that a process of illuviation takes place. However, although the presence of a more or less intensive rooting in the spodosols is mentioned in all descriptions, the influence of its destruction does not seem to have been taken into account. Yet something has to happen to these organic materials.

Our studies have clearly shown that their destruction by the soil fauna and microfauna results in the formation of features, that are present in many spodic horizons. Moreover, the soil fauna can take up and transform the products of the illuviation process into units that are typical for its activity. On the other hand, the transformation of "faunal" units can be so strong that it is quite possible that part of the monomorphic matter originates from these units and not from the litter.

As a conclusion, we can say that two processes are active in the genesis of the spodic B. (1) Illuviation through a dispersed phase, giving rise to the formation of the monomorphic organic matter that is present in the form of coatings and concentrations, and (2) formation of plant remains and polymorphic organic matter, assembled in units, typical for faunal and microfaunal activity; fecal pellets, pellets, aggregates and accumulations.

During the first stages, the second process is predominant, but the presence of the coatings shows that the first process is active simultaneously.

The cementation of the B is the result of an invasion by monomorphic organic matter that is so intensive that the faunal activity is unable to break down the fabric of coatings and bridges, gradually embracing all the sandgrains.

The last stage is the result of the strong faunal and microfaunal activity in the rootmat, developing above the cemented B.

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